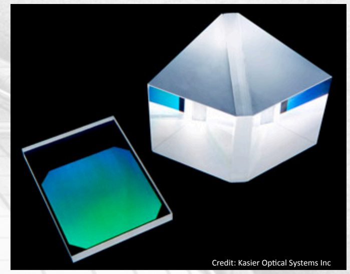
Comparing modelling techniques when designing VPH gratings for BigBOSS

Claire Poppett[1], Patrick Jelinsky[2], Mike Lampton[2], Jerry Edelstein[2], James Arns[2]

[1] Lawrence Berkeley National Laboratory, [2] University ofCalifornia Berkeley, Space Sciences Laboratory, [3]Kaiser optical Systems

Abstract

BigBOSS is a Stage IV Dark Energy based on the Baryon Acoustic Oscillations (BAO) and Red Shift Distortions (RSD) techniques using spectroscopic data of 20 million ELG and LRG galaxies at 0.5<z<1.6 in addition to several hundred thousand QSOs at 0.5<z<3.5. When designing BigBOSS instrumentation, it is imperative to maximize throughput whilst maintaining a resolving power of between R=1500 and 4000 over a wavelength range of 360-980 nm. Volume Phase Holographic (VPH) gratings have been identified as a key technology which will enable the efficiency requirement to be met, however it is important to be able to accurately predict their performance. In this paper we quantitatively compare different modeling techniques in order to assess the parameter space over which they are more capable of accurately predicting measured performance. Finally we present baseline parameters for grating designs that are most suitable for the BigBOSS instrument.



Credit: Kasier Optical Systems Inc

VPH gratings in astronomy

Advantages of VPH compared to Surface Relief (SR):

- higher peak diffraction efficiency ;
- fewer grating anomalies;
- large VPH grating structures, up to and larger than 800 mm in diameter;
- Robust since the grating is encapsulated within the glass.

VPH in astronomy[2] - used in a number of spectrographs in many different forms and environments:

- VPH grisms operated at cryogenic temperature in MOIRCS, a Cassegrain near-infrared instrument of the Subaru Telescope;
- Apache Point Observatory Galactic Evolution Experiment (APOGEE) spectrograph, which uses large, 304 x 508, glass to accommodate an elliptically shaped clear aperture of 290 mm x 475 mm;
- FORS2 at the VLT which has a number of high-throughput VPH grisms;
- Being considered for instruments on many large telescopes, including the Wide Field Optical Spectrograph (WFOS) for the Thirty Meter Telescope (TMT).

Modelling tools

Kogelnik[1]:

- simple method but only deals with 0th and 1st order inside the grating. Ignores diffracted light that is generated in the boundary surface of modulation and non-modulation when the reference beam enters the grating from air or the object beam exits into air from the grating.

Commercially available Rigorous Coupled Wave Analysis (RCWA) code:

- Gsolver™ [3]
- DiPoG™
- GD-Calc™
- GratingMOD™
- MaX-1™
- PCGrate™

Vendor software:

- Usually guaranteed to produce a grating that has efficiency to within 7-10% of their predicted efficiency at a given wavelength

Modelling parameters

line densities	$\nu=1/\Lambda$	<6000 lmm^{-1}
wavelength range	λ	350-2400 nm
modulation variation	Δn	0.02-0.1
gel thickness	d	2- 9 µm

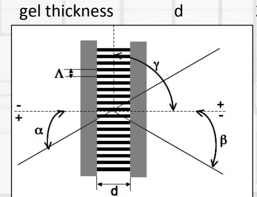


Figure 1: Schematic of VPH gratings including parameter definition

BigBOSS spectrograph

Spectrograph Requirements (from Science Requirements):

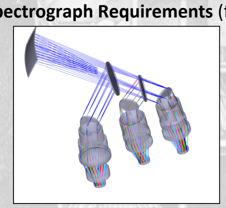


Figure 2: BigBOSS Spectrograph design

- FWHM Spectral Resolution (to resolve OII doublet)
- Throughput (for signal to noise on galaxy)
- 500 fiber slit (to achieve desired number of galaxies)

Spectrograph Design:

- 3 arms to achieve resolution and throughput
- Reflective collimator
- Refractive Cameras
- 4kx4k CCD detectors
- Fibre slit design is based on BOSS design

Slanted gratings

Slanted fringe gratings - Tilting the fringes of the gratings is an effective way of reducing Littrow ghosts in addition to decreasing the gratings size whilst maintaining the efficiency profile of a larger grating

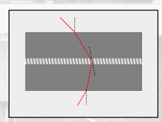


Figure 3: Schematic of a grating with slanted fringes

- When a VPH is illuminated at an angle which does not satisfy the Littrow condition ($\theta_{incident}=\theta_{diffracted}$) the diffraction efficiency profile with respect to wavelength shifts
- ↓ $\theta_{incident}$ w.r.t. normal moves the peak of the diffraction energy to shorter wavelengths
- ↑ $\theta_{incident}$ w.r.t. normal moves the peak of the diffraction energy to longer wavelengths

The change in illumination angle also results in an anamorphic magnification of the beam which is especially desirable if slanted fringes can be used to achieve the diffraction efficiency profile required.

Modelling comparisons and example grating efficiencies

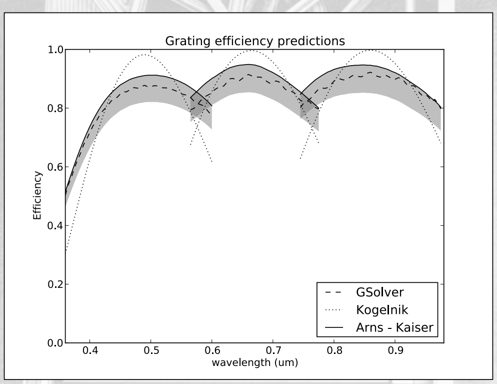


Figure 4: Grating efficiency predictions for gratings with an angular dispersion of 14.3 degrees. Grey area shows manufacturing tolerances

Modelling comparisons:

Grating efficiency predictions made by Kogelnik analysis and Gsolver™ were compared to predictions made by James Arns at Kaiser. Figure 4 shows the grating efficiency as a function of wavelength. Since Kaiser normally guarantees that their gratings will be delivered to within 7-10% of their predicted values, the efficiency predictions of the other two methods were compared to these numbers. Figures 5-7 shows the percentage difference between the efficiencies predicted by Kogelnik analysis and Gsolver™, compared to Arns' predictions.

As is shown in these figures, Gsolver™ predicts the grating efficiency to within the manufacturing tolerances of Arns predictions over our entire wavelength band for our specific parameters. Kogelnik analysis predicts the correct shape of the curve and where the peak in efficiency occurs, however it does not predict absolute efficiencies well enough to be used in this project.

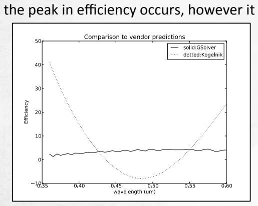


Figure 5: Blue arm – comparison of efficiency predictions made by Kogelnik analysis and Gsolver™ compared to Arns at Kaiser predictions

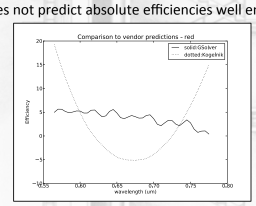


Figure 6: Red arm – comparison of efficiency predictions made by Kogelnik analysis and Gsolver™ compared to Arns at Kaiser predictions

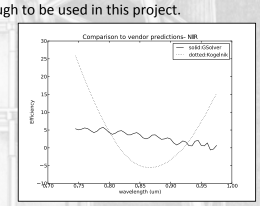


Figure 7: NIR arm – comparison of efficiency predictions made by Kogelnik analysis and Gsolver™ compared to Arns at Kaiser predictions

Conclusions

- VPH gratings have been successfully used in astronomical instrumentation in many projects
- VPH gratings can be designed for BigBOSS which have a high throughput over the entire wavelength band
- Gsolver™ can be used to accurately predict the performance of the gratings
- Kogelnik analysis can be used as a quick tool to determine grating parameters but cannot accurately predict the efficiency performance

The authors gratefully acknowledge the support by the Director, Office of Science, U.S. Department of Energy under Contract No. **DE-AC03-76SF00098.**

BigBOSS

Mapping the Universe

Lawrence Berkeley National Laboratory

References

[1] H. Kogelnik Bell systems technical journal 48, pp. 2909–2947, November 1969.

[2] S. C. Barden, J. A. Arns, and W. S. Colburn, "Volume-Phase Holographic Gratings and their Potential for Astronomical Applications," NASA STI/Recon Technical Report N 99, p. 26271, Mar. 1998.

[3] D Fluckiger - Grating Solver Development Company Dec 2006 : http://www.gsolver.com